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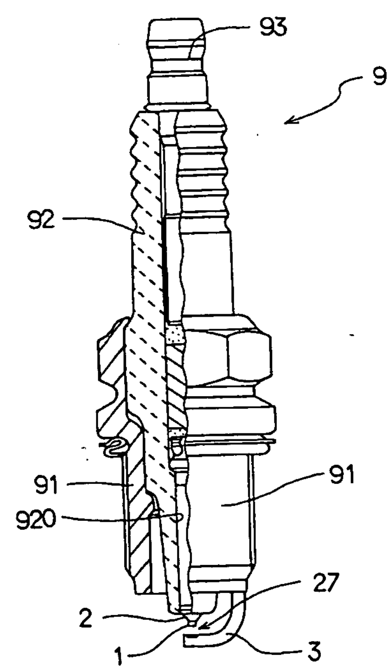
(54) Spark plug for internal combustion engine

(57) In a spark plug for an internal combustion engine, a noble metal chip (1) such as an iridium alloy chip is bonded on the tip of a center electrode (2) made of a material such as nickel by laser beam welding. The noble metal chip (1) contains another noble metal such as rhodium having a melting point lower than that of the noble metal chip. By laser welding, a molten bond (11) containing the noble metal melted thereinto from the noble metal chip (1) is formed at the junction of the noble metal chip (1) and the center electrode (2). Alternatively, the noble metal to be melted into the molten bond (11) may be supplied by a separate noble metal plate. The molten bond thus made has a high bonding strength and a small thermal stress, and thereby durability of the spark plug is improved.

FIG. 2



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BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A to 1C show a process of making a molten bond between a noble metal chip and a center electrode by laser welding;

FIG. 1D is a fragmentary view showing a bonded center electrode as a first embodiment according to the present invention;

FIG. 2 is a half-cross-sectional view showing a spark plug for an internal combustion engine to which the present invention is applied;

FIG. 3 is a fragmentary view showing the bonded center electrode of the spark plug;

FIG. 4 is a graph showing relation between laser energy and bonding strength before and after durability tests;

FIG. 5 is a graph showing relation between the amount of Rh contained in an Ir alloy and the strength of a molten bond formed by laser energy of 5 joule;

FIG. 6 is a fragmentary view showing a center electrode bonded with laser energy of 5 joule;

FIG. 7 is a fragmentary view showing a center electrode bonded with laser energy of 7.5 joule;

FIG. 8 is a fragmentary view showing a center electrode bonded with laser energy of 10 joule;

FIGS. 9A and 9B show another process of making a molten bond between a noble metal chip and a center electrode by laser welding;

FIG. 9C is a fragmentary view showing a bonded center electrode as a second embodiment according to the present invention;

FIG. 10 is a graph showing relation between the amount of Rh contained in a molten bond and bonding strength;

FIG. 11 is a fragmentary view showing a center electrode as a third embodiment having a molten bond which includes an unmolten portion;

FIG. 12 is a fragmentary view showing a center electrode as a variation of the third embodiment;

FIG. 13 is a graph showing relation between laser energy and bonding strength of a molten bond of a center electrode as a comparative example;

FIGS. 14 to 16 are fragmentary views showing a molten bond in the comparative example.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIGS. 1 to 8, a first embodiment according to the present invention will be described. FIG. 2 shows spark plug 9 for an internal combustion engine to which the present invention is applied, and FIG. 3 shows a part of the spark plug including center electrode 2 to which noble metal chip 1 is welded. Referring to FIG. 2, spark plug 9 is composed of insulator 92 having through hole 920 therein, center electrode 2 disposed at the bottom end of through hole 920, metal housing 91 which holds insulator 92 therein, ground electrode 3 attached to metal housing 91 and disposed to face center electrode 2, and terminal 93 for connecting the spark plug to a high voltage source. Center electrode 2 and ground electrode 3 constitute spark gap 27. On the tip of center electrode 2, noble metal chip 1 is bonded by laser welding.

Referring to FIG. 1D, noble metal chip 1 made of an Ir (iridium) alloy having a melting point higher than 2,200 °C is welded to center electrode 2 with molten bond 11 interposed therebetween. A noble metal having a melting point of 1,500 to 2,100 °C and a linear expansion coefficient of 8 to 11 × 10^{-6}/°C is contained in molten bond 11 at a ratio higher than 1 weight percent (wt%). Though the noble metal chip is bonded to the center electrode in this embodiment, it may be bonded to the ground electrode in the same manner as described hereunder.

Referring to FIGS. 1A to 1C, a process of welding noble metal chip 1 to center electrode 2 will be described. In this embodiment, noble metal chip 1 is made of Ir alloy containing rhodium (Rh), the amount of which is varied as explained later. As shown in FIGS. 1A and 1B, noble metal chip 1 is placed on end surface 211 of tip 21 of the center electrode and preliminarily connected to the end surface by resistance welding. Then, laser beam 4 is radiated and focused on a junction between noble metal chip 1 and center electrode 2 as shown in FIG. 1C. Under radiation of laser beam 4, center electrode 2 is rotated so that a whole periphery of the junction is subjected to the laser beam. The junction of noble metal chip 1 and center electrode 2 is melted by the laser beam, forming metal bond 11, and noble metal chip 1 is welded to center electrode 2.

In this particular embodiment, noble metal chip 1 is made of an Ir-Rh alloy (content of Rh is varied), and the diameter of the chip is 0.7 mm and its thickness is 1.0 mm. As the laser a YAG laser is used. Center electrode 2 is made of a nickel (Ni) alloy containing 15.5 wt% chrome (Cr) and 8.0 wt% iron (Fe). The YAG laser energy is varied in three steps, 5.0 joule (J), 7.5 J and 10.0 J.

Spark plugs 9 made as described above were subjected to durability tests. The spark plugs were installed on a 6-cylinder 2000 cc internal combustion engine, and the engine was driven for 100 hours by repeating a cycle consisting of 1 minute idling and 1 minute full throttle operation at 6000 rpm. The durability test results are shown in FIG. 4, in which the laser energy used for making molten bond 11 between noble metal chip 1 and center electrode 2 is shown on the abscissa, and bonding strength of the molten bond in newton (N) is shown on the ordinate. The bonding strength (N) represents a bending strength of molten bond 11. The higher the bonding strength is, the higher bondability is secured and the smaller the thermal stress in molten bond 11 becomes, resulting in a longer life of the spark plug. Noble metal chip 1 of the spark plugs used in the dura-

7. In the case of laser energy 10.0 J (FIG. 16), molten bond 81 has large depression 811 at its periphery and includes voids 83 therein (compare with FIG. 8).

For a further comparison purpose, other comparative samples are made in which the noble metal chip made of Ir containing 5 wt% of iron (Fe), vanadium (V), boron (B) or titanium (Ti) is used. The reason these metals are selected is that their linear expansion coefficient lies between those of nickel (Ni) and iridium (Ir). The comparative samples are subjected to the same durability test. The bonding strength of each sample is lower by 5 to 20 % than that of the embodiments of the present invention which include Rh in the molten bond. On observation of the shape of the molten bond after the durability test, small cracks are found in the molten bond. The reason for this may reside in that the metals, Fe, V, B and Ti are oxidized easier than Rh, and accordingly some oxides are formed in the molten bond during the durability test. Also, these metals are not melted into the molten bond with their entire volume and form metal compounds, such as Ir_3Ti, which have a discontinuous linear expansion coefficient, and accordingly the thermal stress in the molten bond may not be sufficiently released.

In the foregoing embodiments of the present invention, an Ir alloy having a melting point higher than 2,200 °C is used as a noble metal chip to be connected to the tip of the center electrode. If the melting point is lower than that, the spark gap is excessively widened while the spark plug is used, and the widened spark gap requires a higher sparking voltage. It is preferable to use such an Ir alloy that has a melting point lower than 2,600 °C to have a 100 °C margin below the boiling point 2,700 °C of nickel (Ni) which is the material of the center electrode. The Ir alloy may be any one of the alloys which contain at least either one of the following metals: platinum (Pt), palladium (Pd), rhodium (Rh), gold (Au), nickel (Ni) and ruthenium (Ru). Also, the Ir alloy may contain yttria (Y_2O_3) or zirconia (ZrO_2).

The molten bond is formed as an alloy containing materials of the noble metal chip such as Ir, the center electrode such as Ni and other noble metals such as Rh added to the noble metal chip or placed on the center electrode. More than 1 wt% of the added or placed noble metal having a melting point of 1,500 to 2,100 °C and a linear expansion coefficient of 8 to 11 × 10^{-6}/°C is contained in the molten bond. If the melting point is lower than 1,500 °C, a large depression is formed around the molten bond when the laser energy is high, because the melting point becomes close to that of Ni which is 1450 °C. On the other hand, if the melting point is higher than 2,100 °C, only Ni is melted without melting the noble metal when the laser energy is low, because both melting points of Ni and the noble metal are too much apart, which results in that the thermal stress is not released in the molten bond. The lower limit of the linear expansion coefficient of the added noble metal (8 × 10^{-6}/°C)is close to that of the noble metal chip, and the upper limit (11 × 10^{-6}/°C) is close to that of the center electrode. If the linear expansion coefficient of the added noble metal is below the lower limit or above the higher limit, the thermal stress cannot be released sufficiently in the molten bond. The amount of the noble metal contained in the molten bond is preferably in a range from 1 wt% to 10 wt%. If it is lower than 1 wt%, the bonding strength is decreased through a long time operation in a heat cycle at high and low temperatures. A higher content of the noble metal exceeding 10 wt% makes the spark plug too expensive.

In the process of the laser welding, the center electrode material such as Ni and the added noble metal such as Rh form an alloy such as Ni-Rh, and then this alloy and the noble metal chip such as Ir form a final alloy such as Ni-Rh-Ir constituting the molten bond. Because of the presence of Rh between Ir and Ni, it becomes easier for Ir to be melted into the molten bond even when the laser energy is low. This is because the melting point of Ir-Rh is lower than that of Ir, and Ir is melted into the molten bond in a form of Ir-Rh. Rh has such a characteristic that it melts into Ir with its entire volume. On the other hand, when the laser energy is high, evaporation of Ni is suppressed by the presence of Rh. This is because the melting point of Ni-Rh is higher than that of Ni. Therefore, formation of the depression around the molten bond and formation of voids in the molten bond are suppressed. As a result, the noble metal chip and the center electrode can be firmly bonded by the laser welding without much depending on the laser energy. Also, the thermal stress at the junction is greatly relieved by the molten bond. Accordingly, a higher durability of the spark plug is realized according to the present invention.

It is preferable to use metals such as Pt, Pd or Rh as the added or placed noble metal. It is also preferable to use a Ni alloy containing Fe and Cr as the center electrode material to avoid oxidization of the center electrode surface. Preferably, the thickness T of the molten bond in which more than 1 wt% of the added or placed noble metal is contained is made thicker than 0.2 mm. This assures that the bondage is made perfect and the thermal stress in the molten bond is made sufficiently low.

While the present invention has been shown and described with reference to the foregoing preferred embodiments, it will be apparent to those skilled in the art that changes in form and detail may be made therein without departing from the scope of the invention as defined in the appended claims.

In a spark plug for an internal combustion engine, a noble metal chip (1) such as an iridium alloy chip is bonded on the tip of a center electrode (2) made of a material such as nickel by laser beam welding. The noble metal chip (1) contains another noble metal such as rhodium having a melting point lower than that of the noble metal chip. By laser welding, a molten bond (11) containing the noble metal melted thereinto from the

FIG. 1A

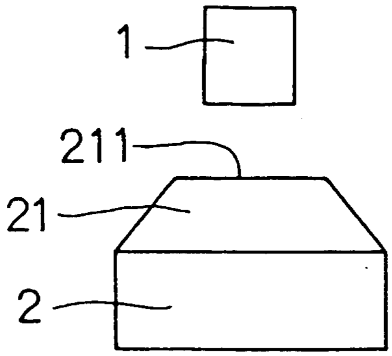


FIG. 1B

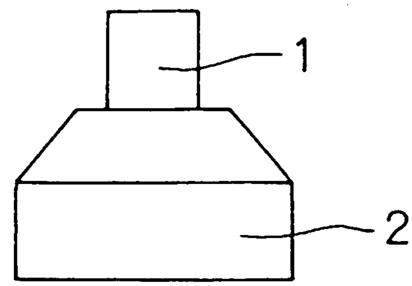


FIG. 1C

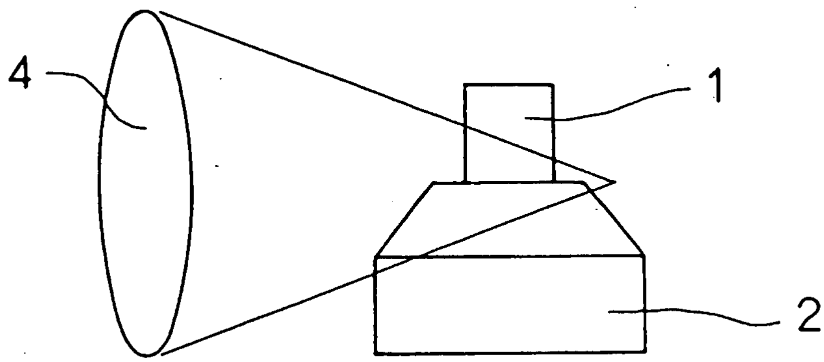


FIG. 1D

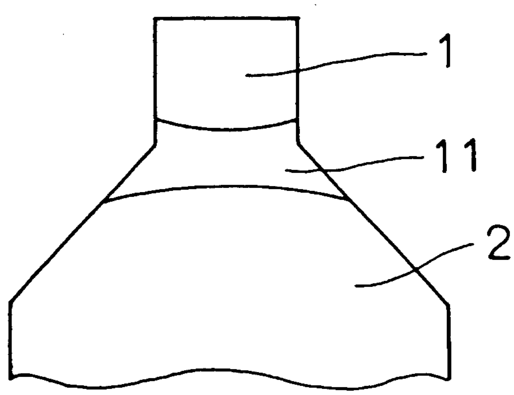


FIG. 2

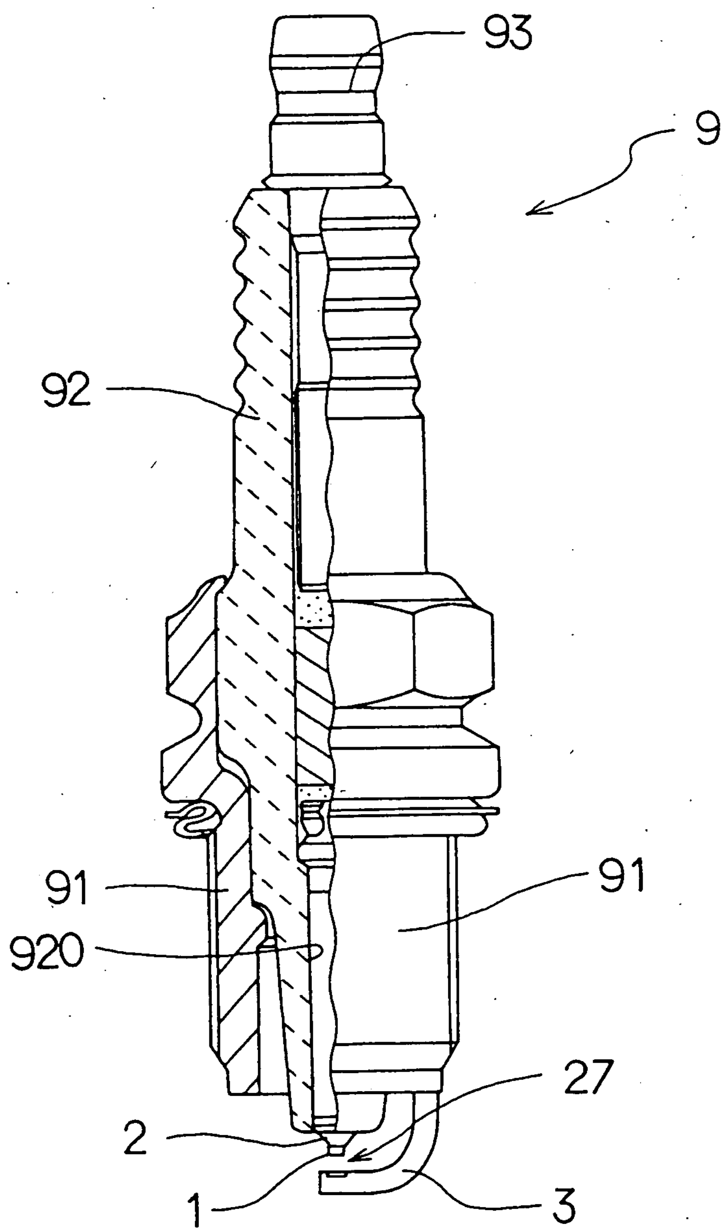


FIG. 3

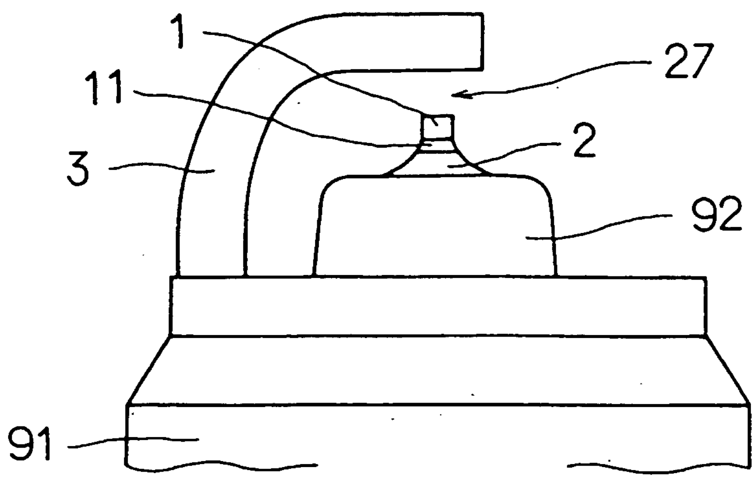

1
27
11
2
3
92
91

FIG. 4

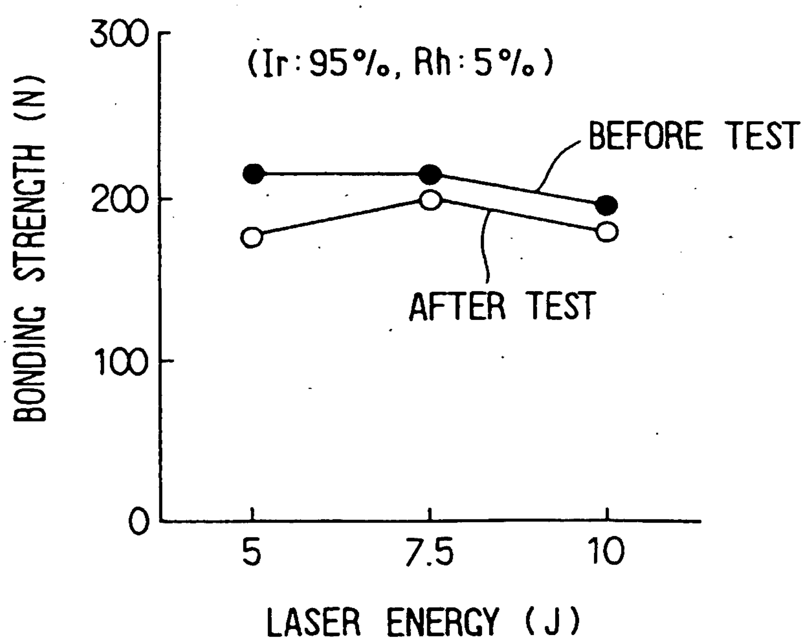

300
200
100
0
(Ir: 95%, Rh: 5%)
BEFORE TEST
AFTER TEST
BONDING STRENGTH (N)
5
7.5
10
LASER ENERGY (J)

FIG. 5

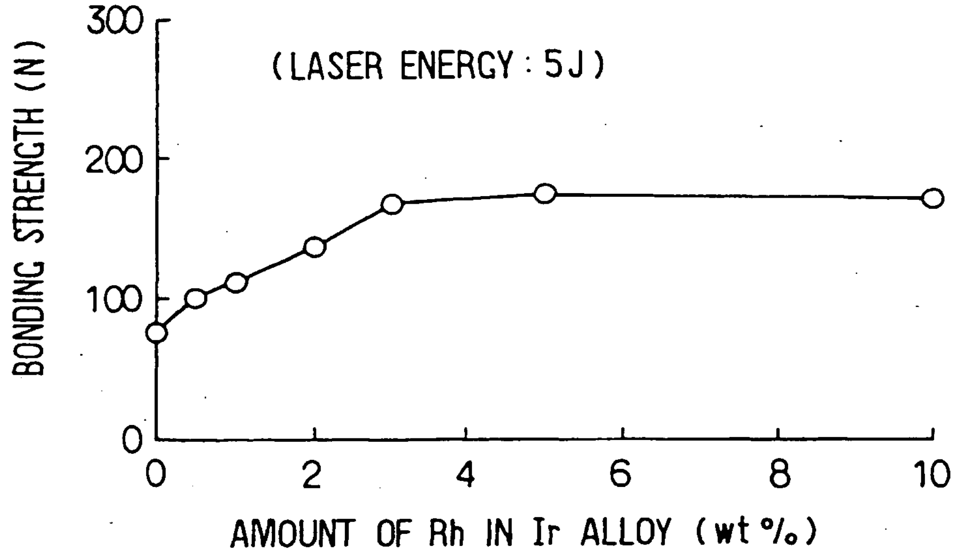

BONDING STRENGTH (N)
300
200
100
0
(LASER ENERGY : 5J)
0
2
4
6
8
10
AMOUNT OF Rh IN Ir ALLOY (wt%)

FIG. 6

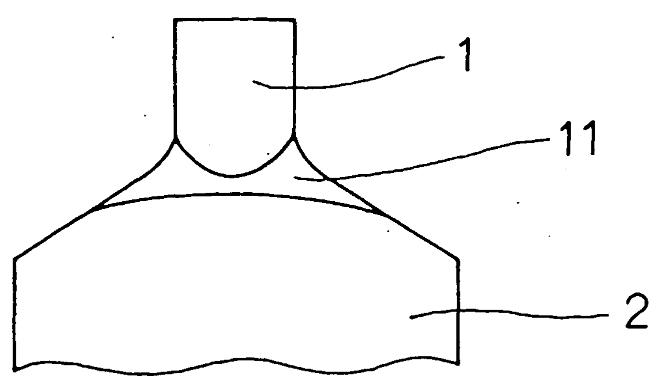

1
11
2

FIG. 7

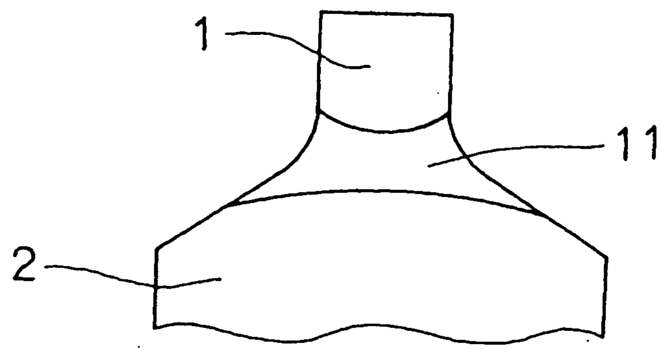


FIG. 8

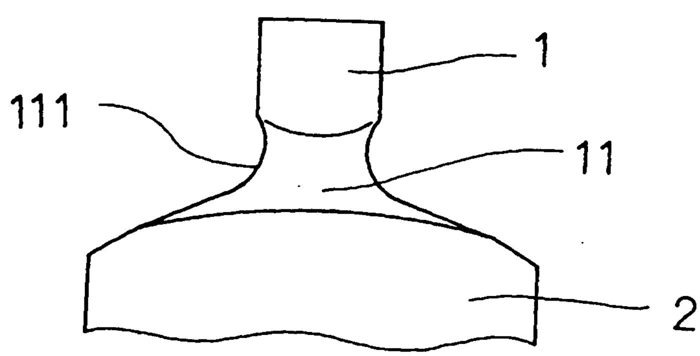


FIG. 9A

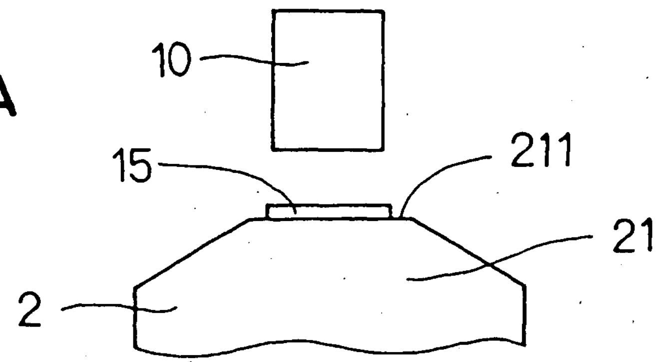


FIG. 9B

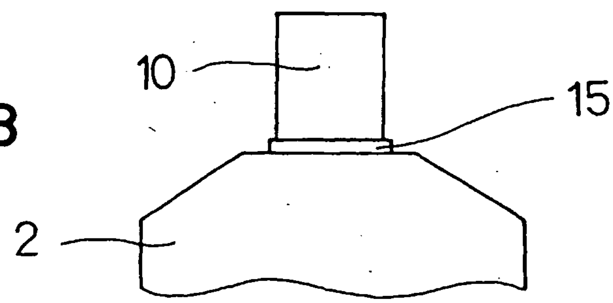


FIG. 9C

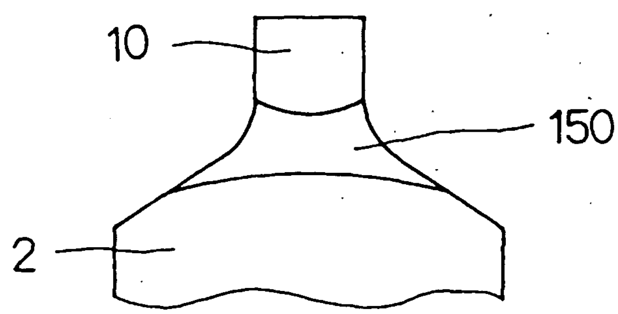


FIG. 10

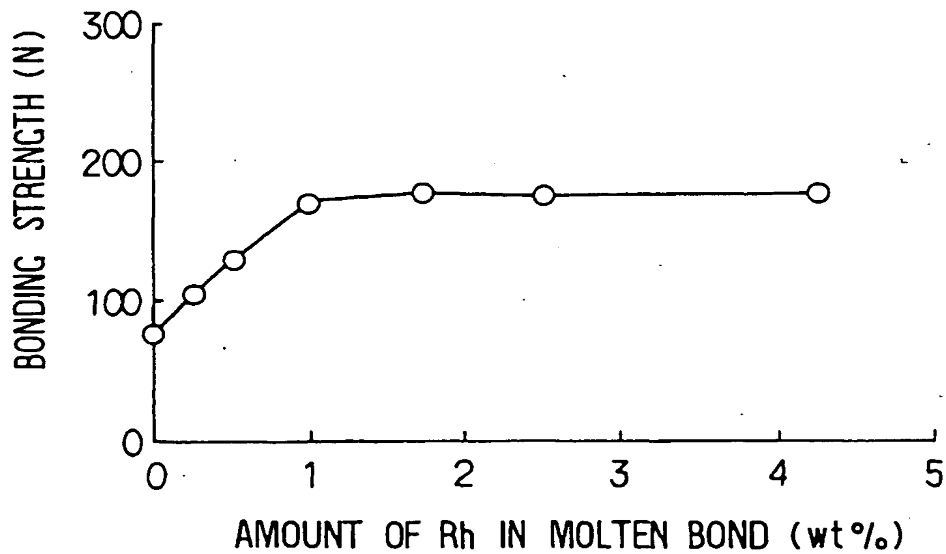

BONDING STRENGTH (N)
300
200
100
0
0
1
2
3
4
5
AMOUNT OF Rh IN MOLTEN BOND (wt%)

FIG. 11

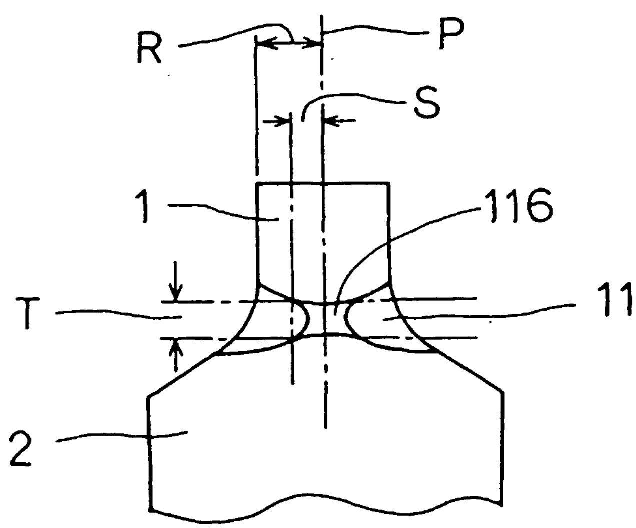

R
P
S
1
116
T
11
2

FIG. 12

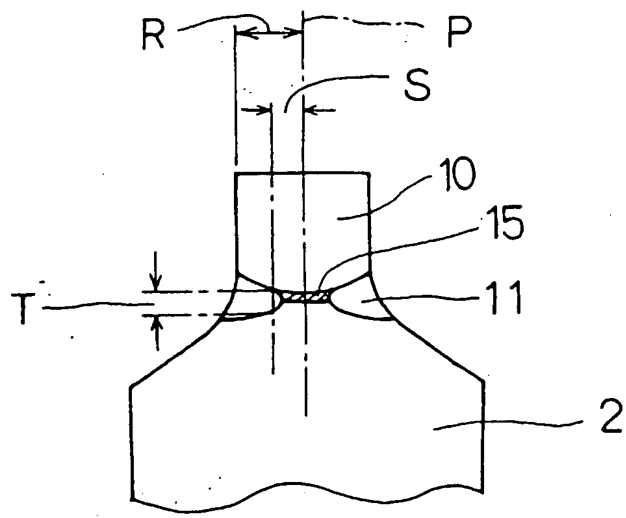

R
P
S
10
15
11
T
2

FIG. 13

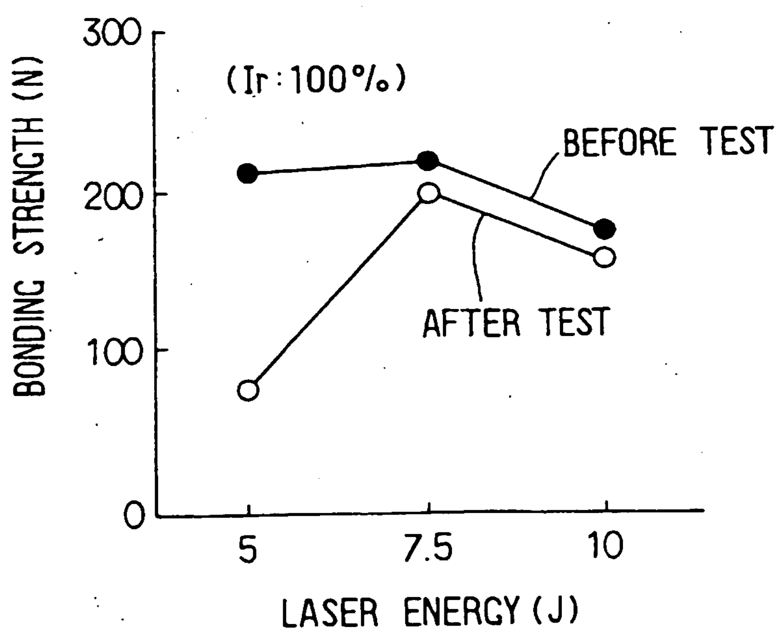

300
200
100
0
BONDING STRENGTH (N)
(Ir : 100%)
BEFORE TEST
AFTER TEST
5
7.5
10
LASER ENERGY (J)

FIG. 14

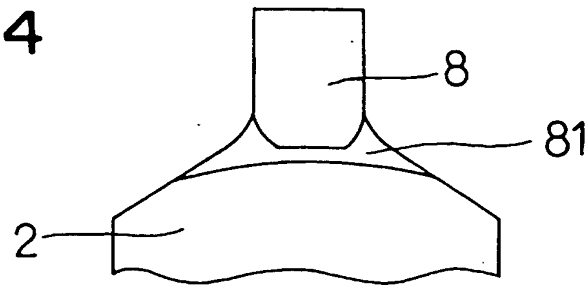


FIG. 15

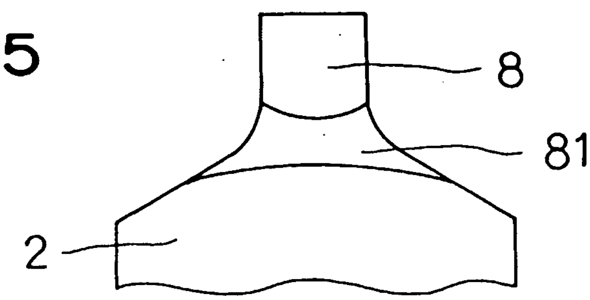
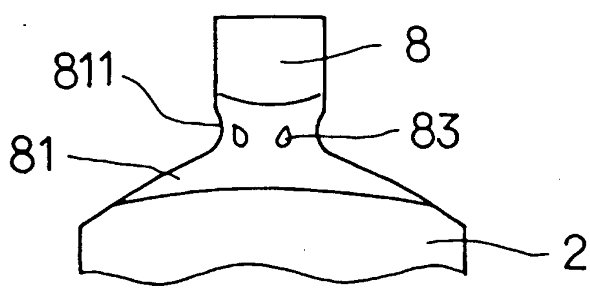


FIG. 16



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 10 2819

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	US 5 578 895 A (OSHIMA TAKAFUMI) 26 November 1996 * column 2, line 50 - column 3, line 11; figure 1 *	1	H01T13/39
A	EP 0 635 920 A (NGK SPARK PLUG CO) 25 January 1995		
A	US 5 461 210 A (MATSUTANI WATARU ET AL) 24 October 1995		
A	US 4 581 558 A (TAKAMURA KOZO ET AL) 8 April 1986		

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

H01T

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	9 July 1998	Bijn, E

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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